Pixel Testbeam Status at LBL

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Preliminary Results from April H8 Testbeam:

- Status of Telescope reconstruction and alignment

- Results on timing

- Results on pulse height distributions

- Results on cluster sizes

- Results on resolutions

- Results on efficiencies

## Many unresolved issues - results are very preliminary !

Reminder of LBL Pixel Chip Configuration

LBL Analog Readout Pixel Prototype:

- Fabricated 12 column by 64 row array of 50μ x 536μ pixels. It has negative polarity inputs, analog readout, and a complete functional prototype of LHC-capable peripheral logic, in the HP 0.8μ 3-metal process. Chips returned Jan 97, with two minor layout errors.
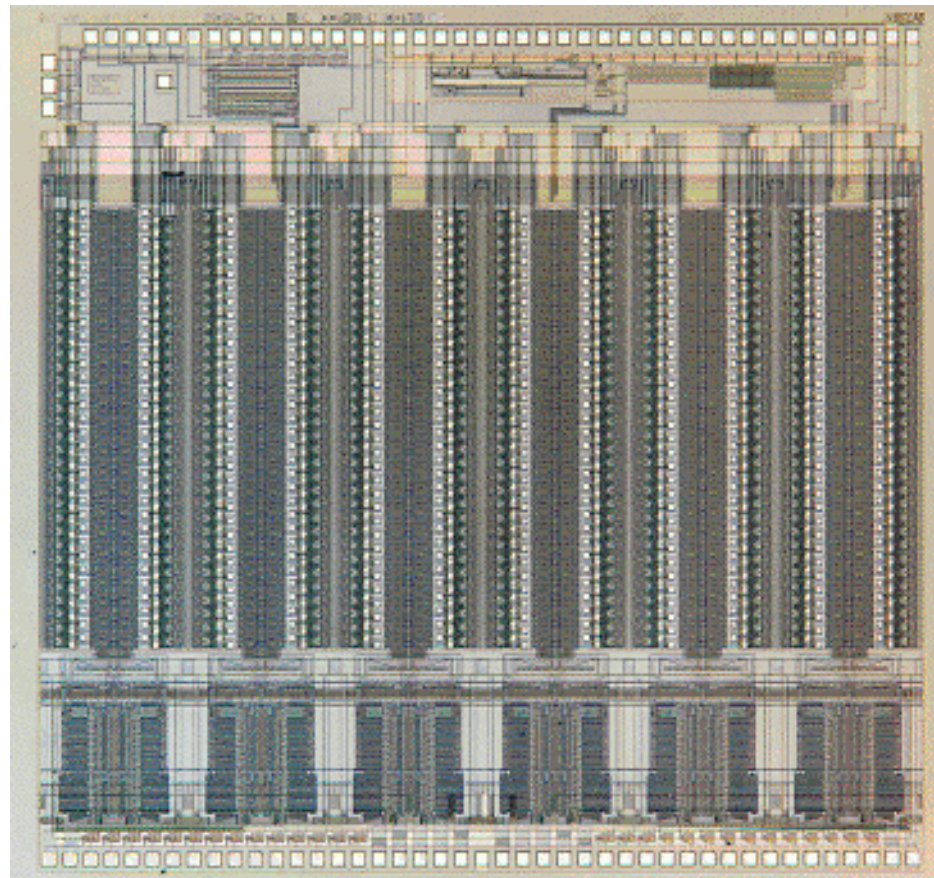
- Arrays were bump-bonded by Rockwell/Boeing, using 25μ Indium bumps, to bricked n-pixel on p-bulk detectors fabricated at LBL. Assemblies available at LBL in Mar. 97.
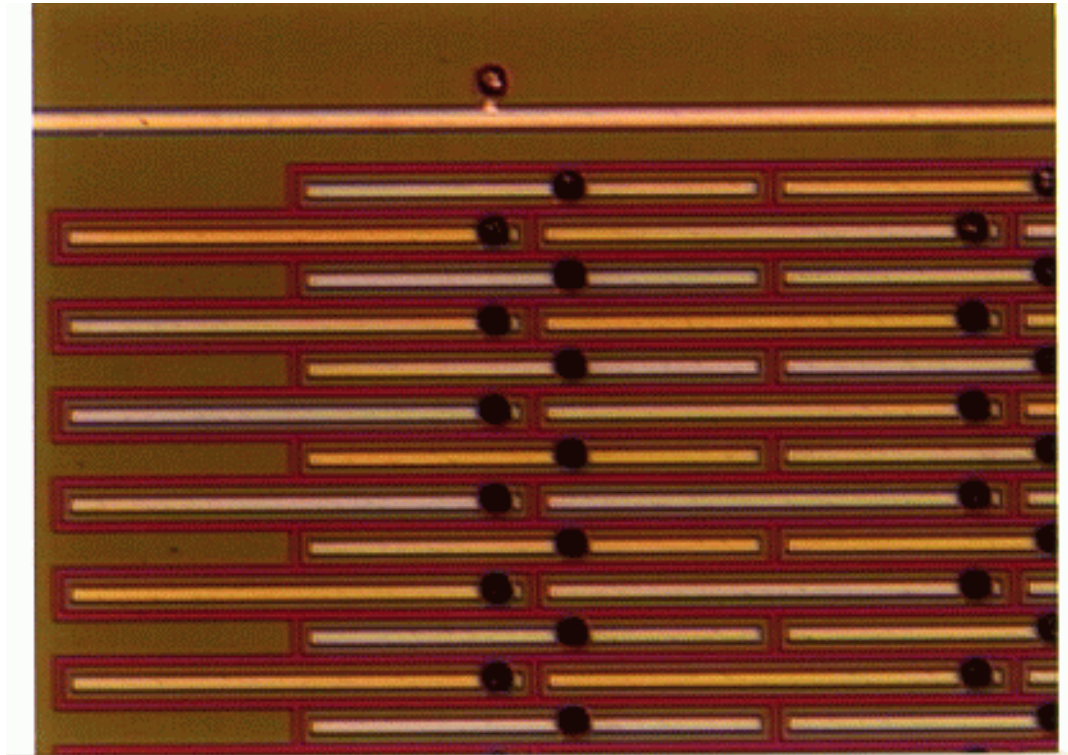
- Arrays with/without detectors were characterized using complete VME-based readout system to study threshold, charge measurement, and timing uniformity:

  → Threshold uniformity < 200e (without) and < 400-500e (with) detectors

  → Timing uniformity < 1 ns, but timewalk significantly worse with detectors ("in-time" threshold is acceptable for 50 ns, but not for 25 ns)

  → Charge measurement uniformity was relatively poor (≈ factor 2 variations)

H8 Test Beam Setup

Chip/detector assemblies in ATLAS test beam in Apr. 97:
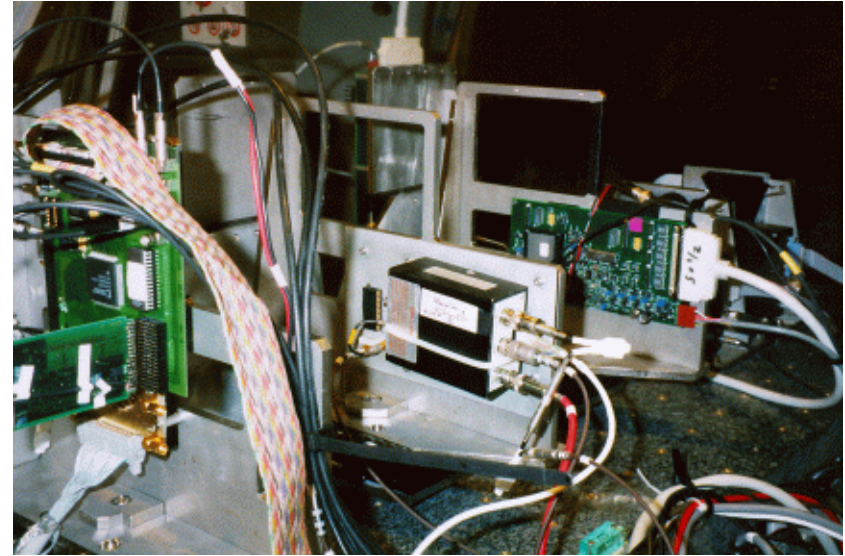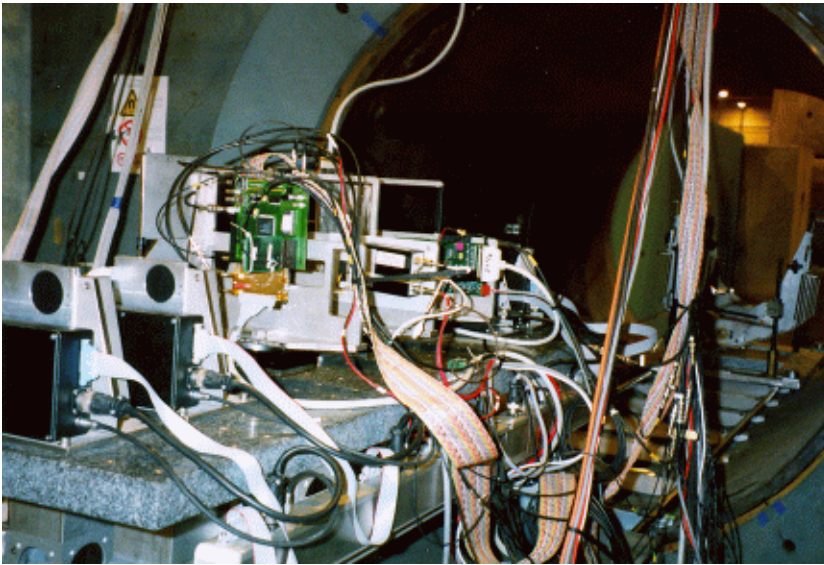
Test Beam setup in H8:

- Four pairs of 50μ strips in x-y planes with slow analog read-out (Viking), providing 1-2μ point resolution

- Small silicon diode (5x5 mm) in trigger to select tracks in pixel arrays (3x6 mm)

- Superconducting dipole providing 1.5T vertical field

- Support stages with rotation/translation for Bonn/CPPM and LBL chips, which were operated simultaneously with common 40 MHz clock.
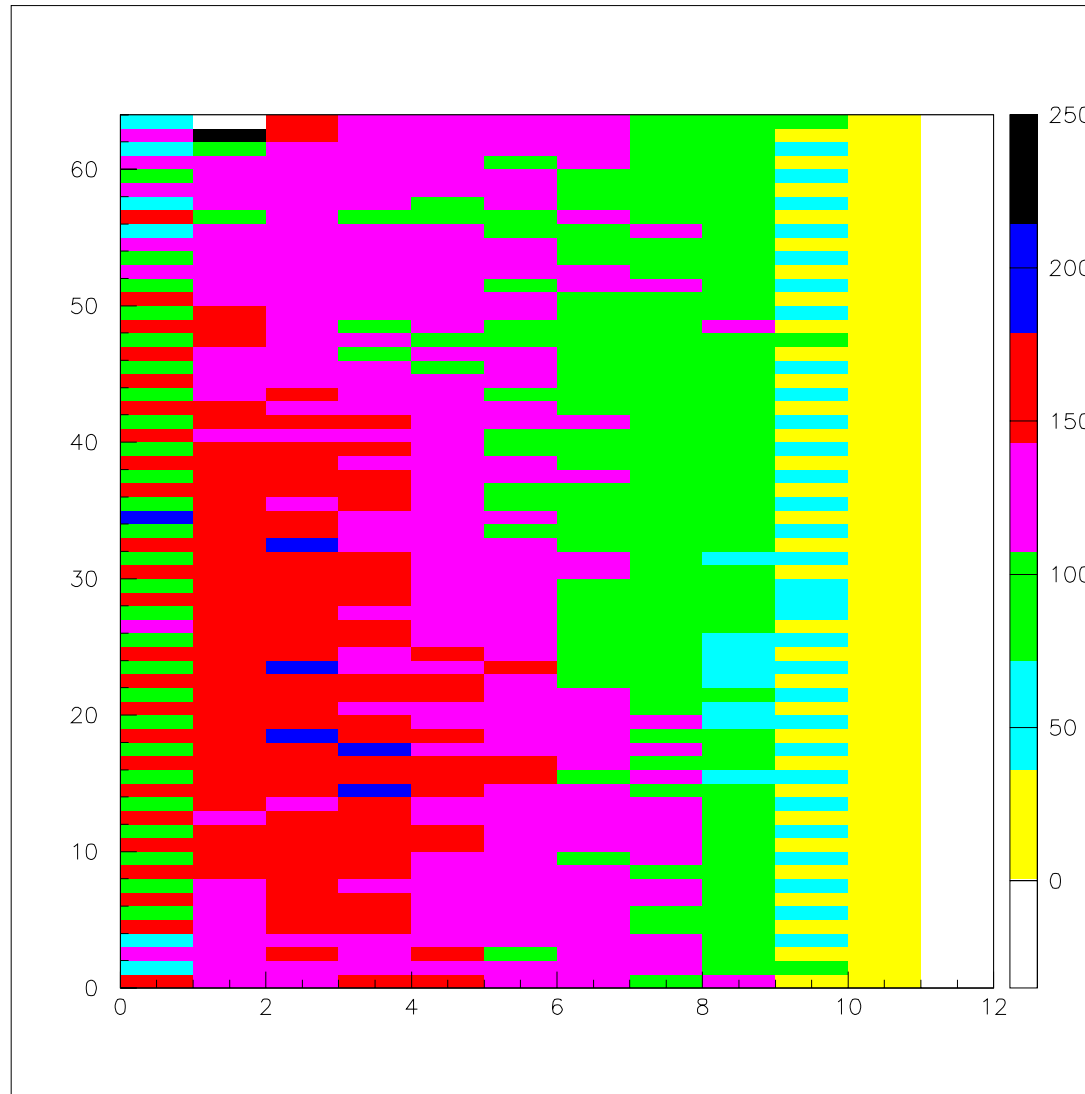
Preliminary Test Beam Results

Chips operated with threshold of ≈ 4Ke, and were very clean, with typically no extra pixels hit:

event display, V = 50, B = θ = 0, Φ = 30
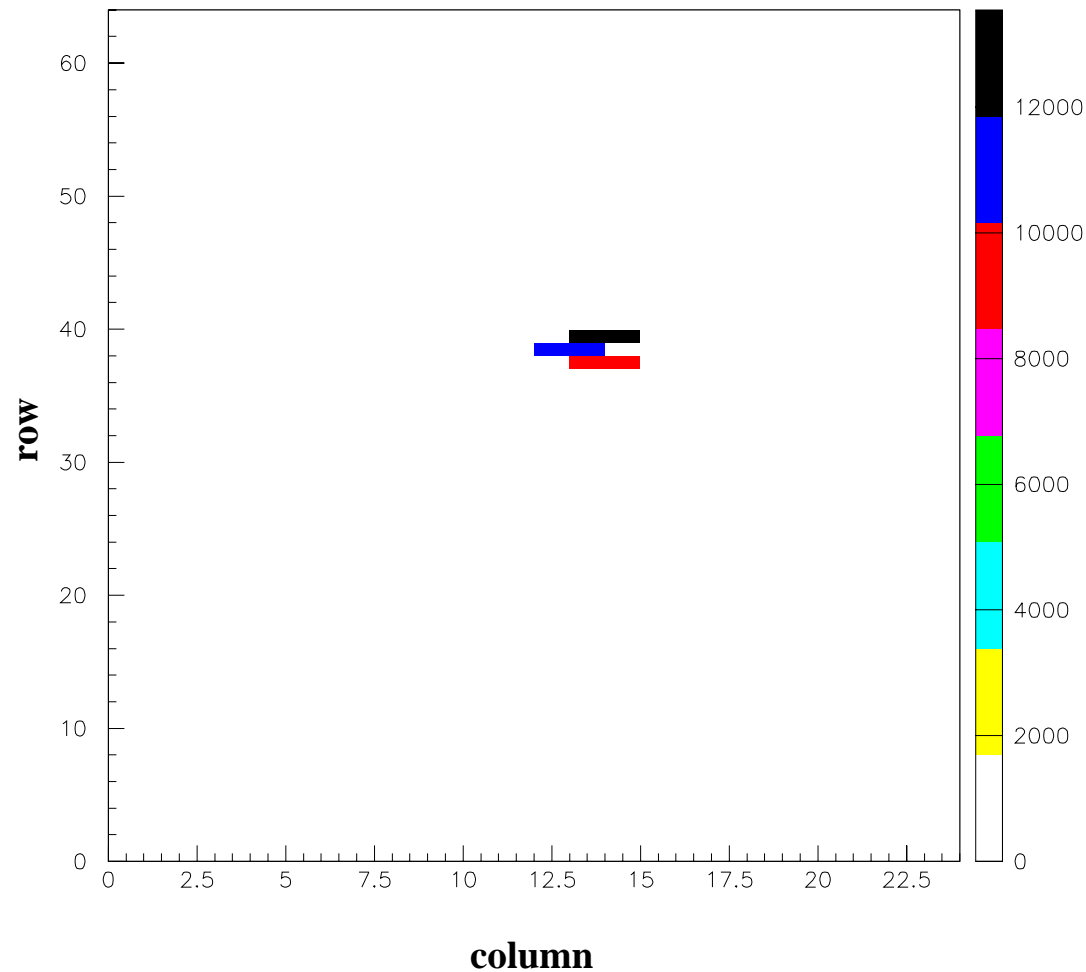
Hit map shows that all 703 channels in 11 functional columns are working (one pixel has no front-end circuitry for test purposes):

Strip Telescope Analysis

Initial analysis code from Thierry Mouthuy

- Almost completely re-written for our understanding...

Initial track finding algorithm was very naive, but useful:

- Reconstruct tracks using highest pulse height clusters in each plane, ignoring all other combinations

- This algorithm has been used to establish a preliminary alignment, which includes the following variables (not the optimal choice of coordinates !):

  → Strip planes have (x,y,z) offsets and (x,y,z) rotations plus (x,y) strip skew ("non-orthogonality") angle. The (x,y) rotations are presently ignored as they are higher order effects

  → Pixel plane has (x,y,z) offsets and (z) rotation plus overall detector angle/orientation (phi/theta tilt).

Initial alignment constants evaluated for each run (mainly for pixel chip itself !)

- Typical residuals for strip clusters are 3-5μ, which is worse than expected given the lack of apparent systematics in the data

## First observation: multiplicities in telescope are very high !

- Suspect beam intensity was too high (sensitive time of Viking readout ≈ 10 μs !)
- Caused us to work on combinatoric track finding algorithms as well

Strip Telescope Performance
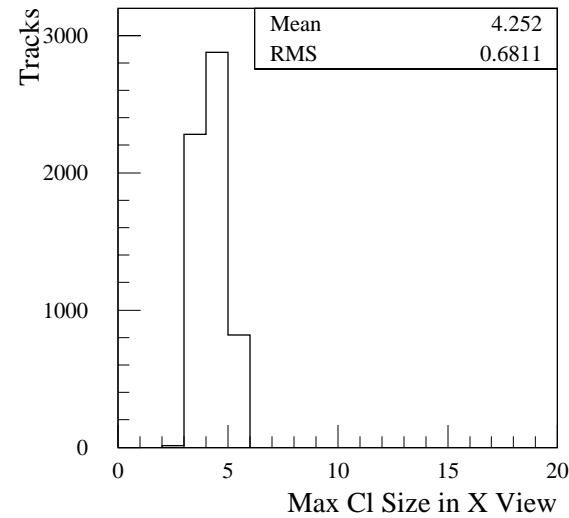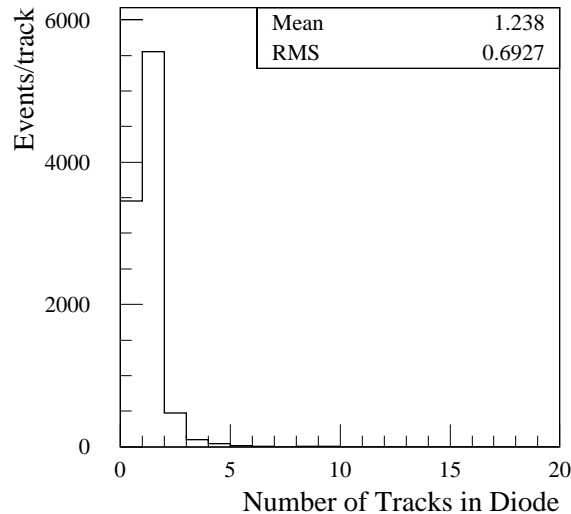
Define improved track finding:

- Consider list of up to 20 strip clusters per plane

- Loop over all pairs of clusters in plane 1 and 3 to define a narrow road (150µ) in x or y, then inspect other planes looking for clusters to add to candidate track.

  Require hits in all active planes for each candidate, and track with overall $\chi^2 < 10$ per DOF

- Select best candidates based on χ^2 cut, typically about 1.5 per DOF

- Have now added "quality" cuts: strip cluster width (< 6), strip cluster charge (> 50). which significantly reduce track multiplicity while retaining good tracks.

Observed χ^2 distribution and multiplicity for typical run:
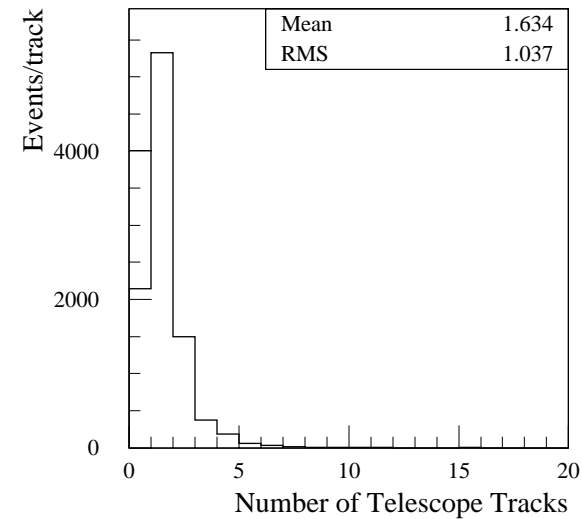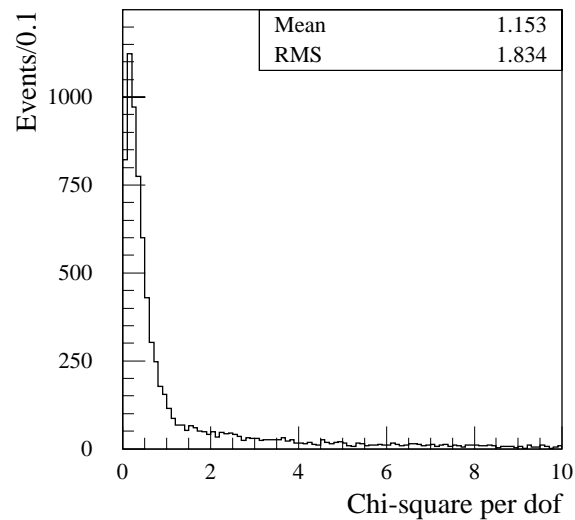
# Observe very large track multiplicity, even after $\chi^2 < 10$ cut.

Observed multiplicity inside of PIN diode fiducial region, and observed strip cluster width:

Mean	1.238
RMS	0.6927

(Events/track vs Number of Tracks in Diode)

Mean	4.252
RMS	0.6811

(Tracks vs Max Cl Size in X View)

Clearly the large cluster width is a cause for concern (thresholds too low ?), and it is unlikely that position estimator is optimized for this data !

- Presently studying clustering algorithms and performance versus multiplicity, etc.
- Present algorithms already use "quality cuts" on strip cluster width and charge, which improves track quality and reduces track multiplicity.

Example plot showing change in pixel x (φ, or narrow direction) residuals versus cluster size.
# Left plot is .le.4, and right plot is .ge.5:
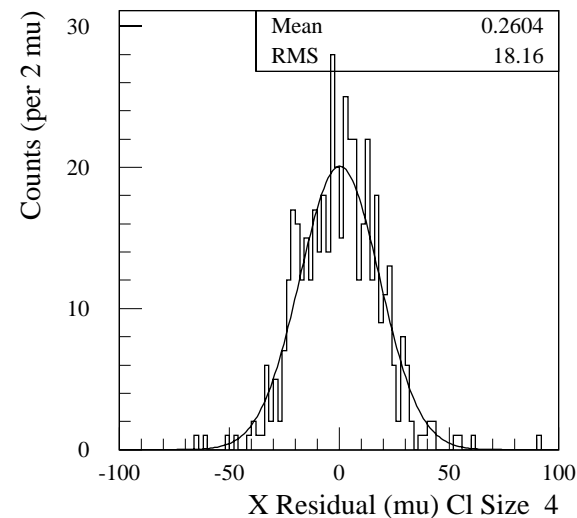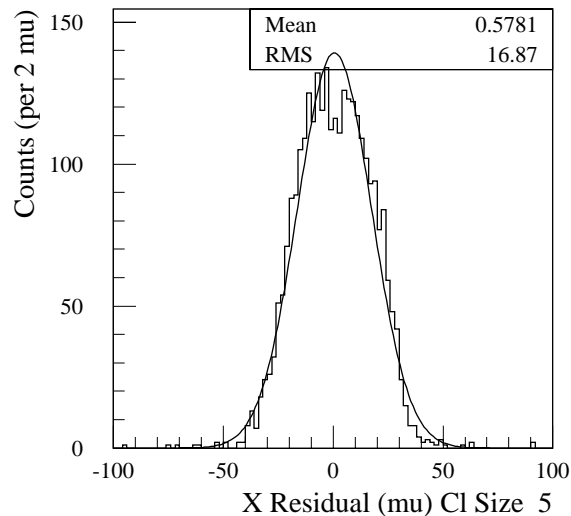
Observe quite different matching resolution, suggesting significant problem(results are much worse without strip cluster size requirement)

Timing Studies

## During H8 run, read out 4 crossings worth of data:

- Timed so that large charges appeared in first crossing. Compare "NTag" (crossing counter) with TDC measuring clock phase ($\approx$ 50 ps per cnt ?). Observe expected correlation, but not necessary to correct (may lose a little off front edge):

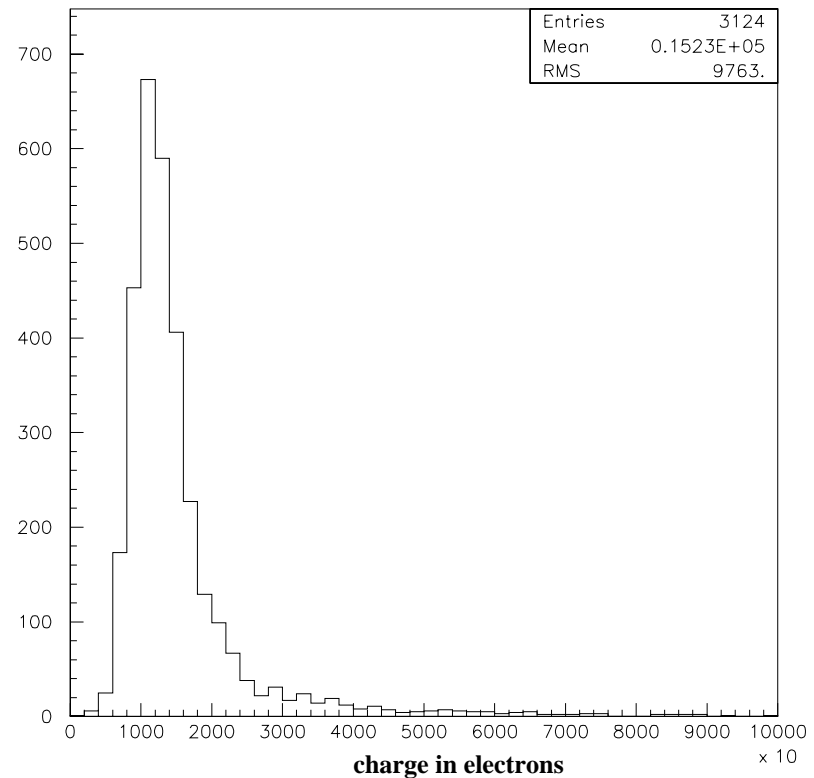**trigger TDC vs time bucket of highest charge pixel**
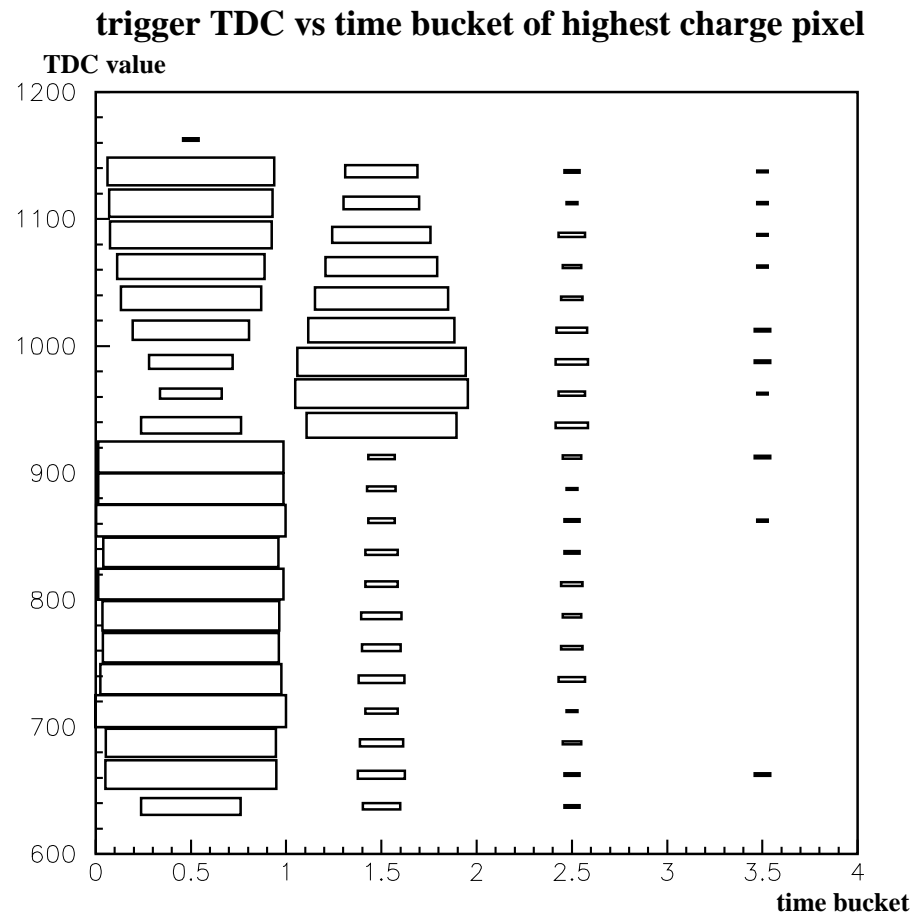
Pulse Height Measurements

Due to charge measurement non-uniformities, apply per-pixel corrections, then plot charge distribution. Plots shown are for VBias = 50 V and 10V, without requiring track:

cluster charge distribution, 50 V, B = Φ = θ = 0
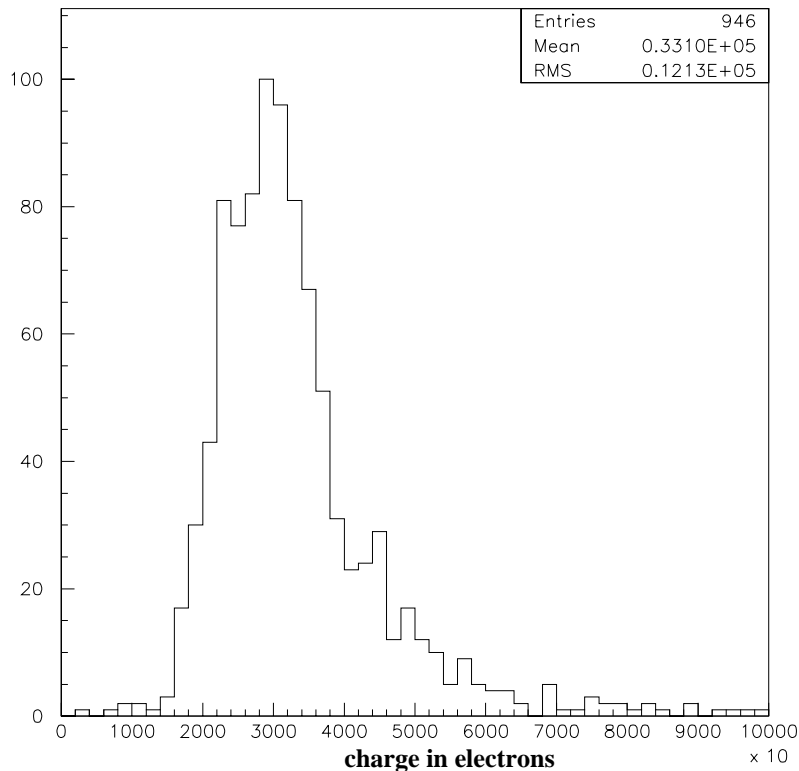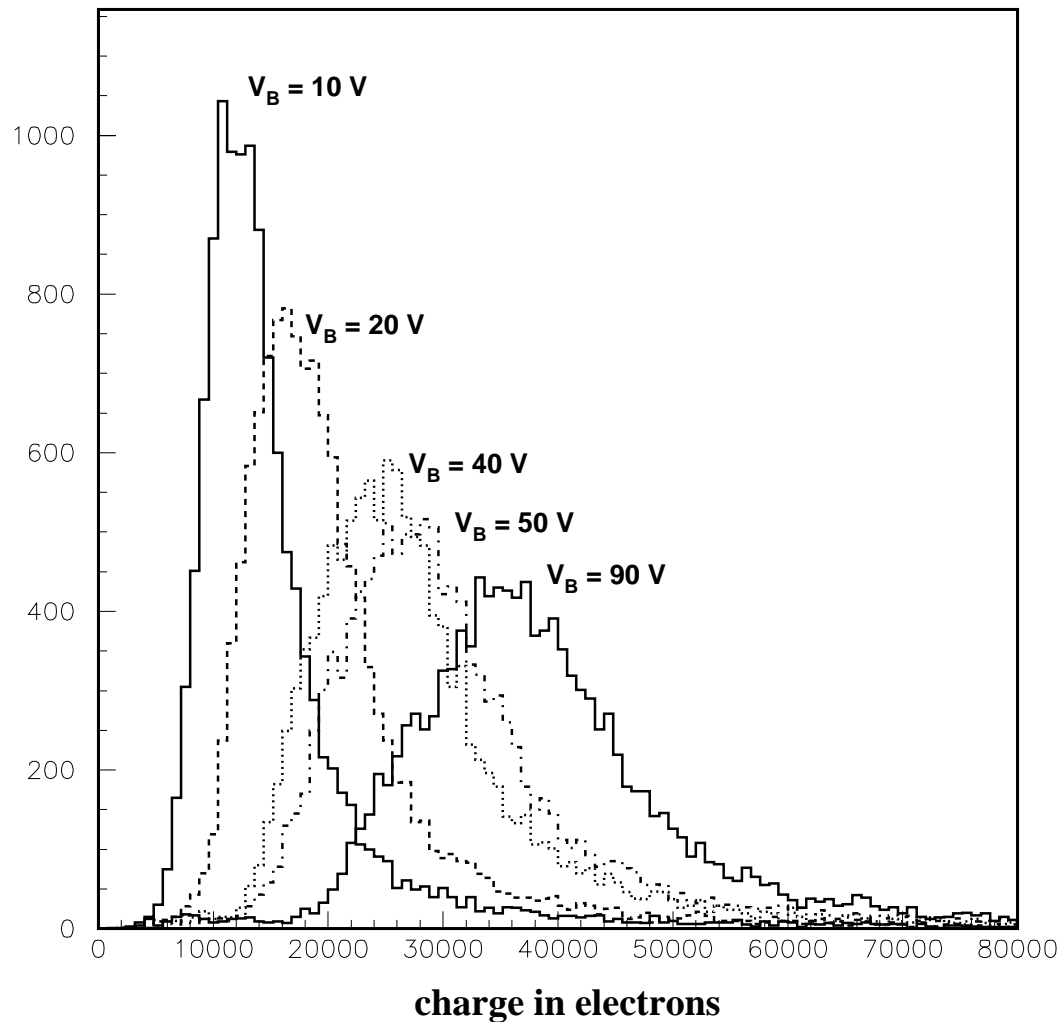
cluster charge distribution, 10 V, B = Φ = θ = 0

Expect full-depletion for 300μ is at about 75V, but may vary significantly in practice...

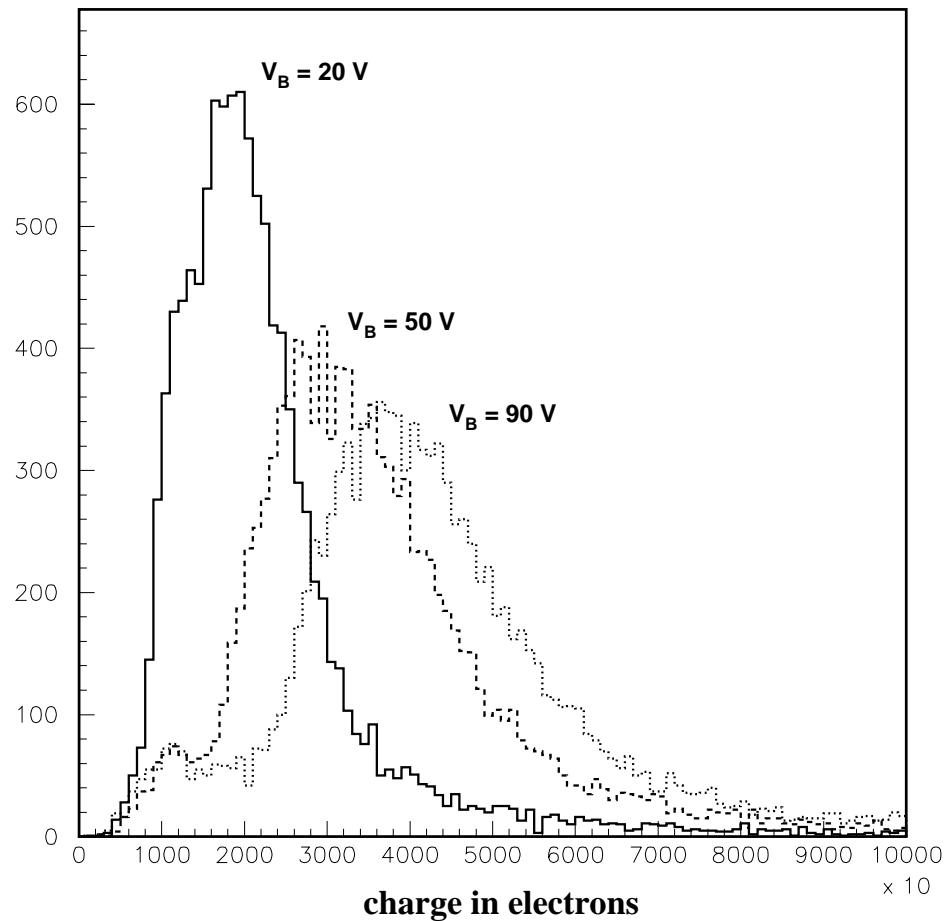# Pulse height plots for different bias voltages at 0 degrees:

cluster charge distribution, B = Φ = θ = 0

Using pulse height, assume 90V is fully depleted, then 50V ≈ 3/4, 20V ≈ 1/2, 10V ≈ 1/3

■
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Pulse height plots for different bias voltages at ϕ = 30 degrees (modest change in path: $\Delta L \approx$ 15%):

cluster charge distribution, B = 0, Φ = -30

Default scale, estimated from probing $C_{cal} \approx$ 6fF, probably too large by 50 % !

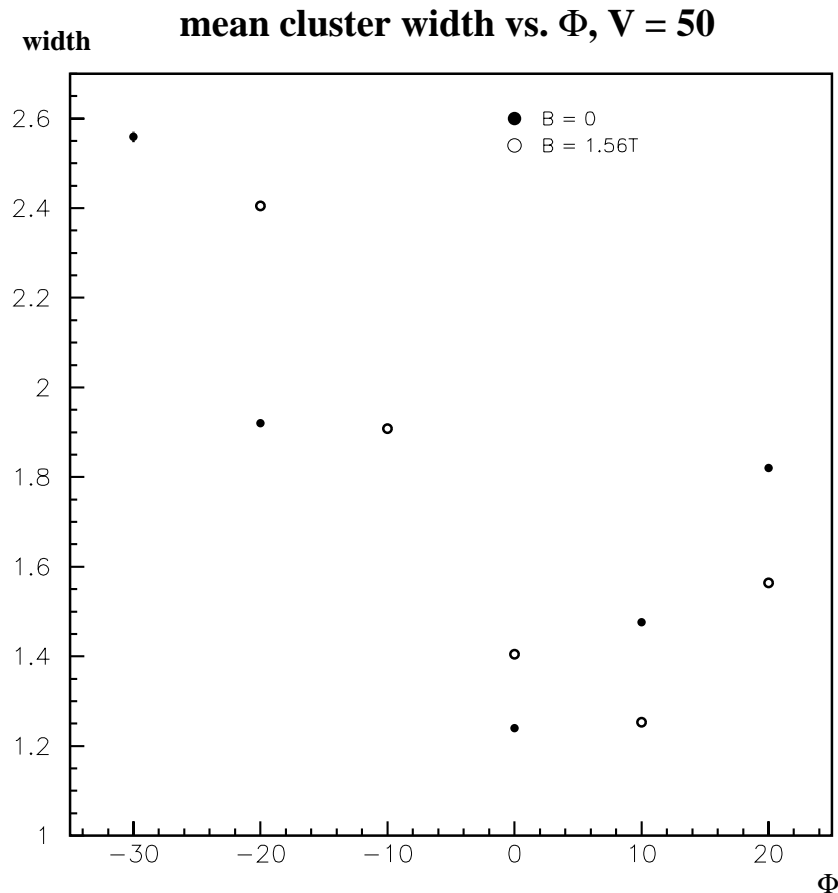# Cluster Width Analyses

Two interesting analyses to perform:

- Compare cluster width in ϕ (number of pixels hit) versus ϕ for B=0 and B=1.56T

  → This will provide an estimate of the Lorentz angle (expected to be ≈ 12 degrees when collecting electrons) by measuring the amount of "tilt" in the charge cloud.

  → These measurements were made with 50V bias (≈ 3/4 depleted)

- Compare cluster widths for large angle data (ϕ = 30 degrees with B = 0) run to measure length of tilted charge cloud, and hence depletion depth

Present preliminary results for each measurement:

- Made without explicit track requirement - only require one pixel cluster in the event, and require that it is not close to the edge of the fiducial region

Cluster Width versus Tilt Angle

Compare cluster width versus ϕ tilt with B=0 and B=1.56T:

mean cluster width vs. Φ, V = 50

width

Analysis not yet quantitative, but find fair agreement with expected Lorentz angle (see perhaps 10-14 degrees by eye...)

# Cluster Width versus Bias Voltage

Compare runs taken at ϕ = 30 degrees (projected charge cloud width for 300μ silicon is 150μ, ignoring diffusion, which we find to be 5-7μ) and VBias = 20V, 50V, 90V:

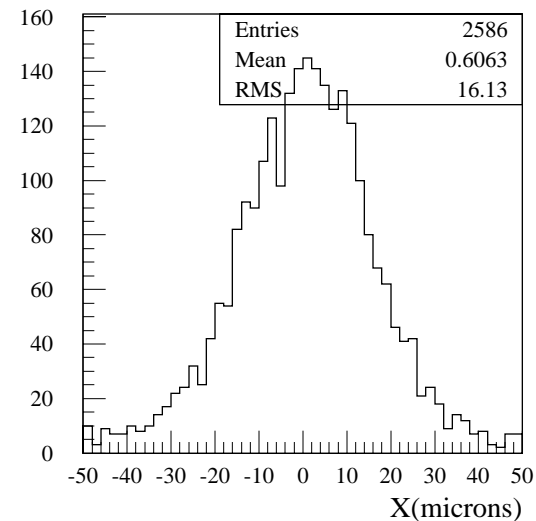mean cluster width vs. V_B, $\Phi = 30$, B = 0
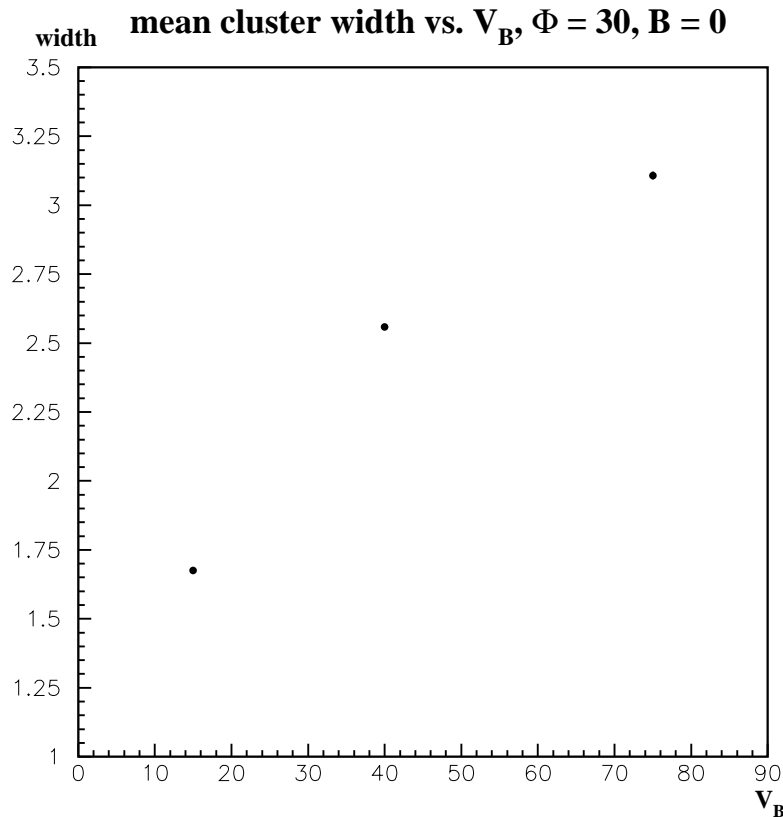
Estimate that fully-depleted 300μ silicon would give $\approx$ 3.5 (must include threshold effects, Landau fluctuations and diffusion to really predict this...)

Resolution Studies

Using preliminary alignments, find hit matching efficiency ≈ 98%, with resolutions as expected (depletion ≈ 150μ):
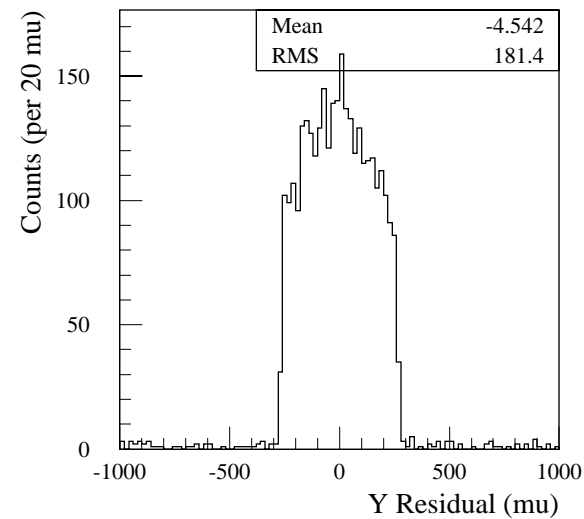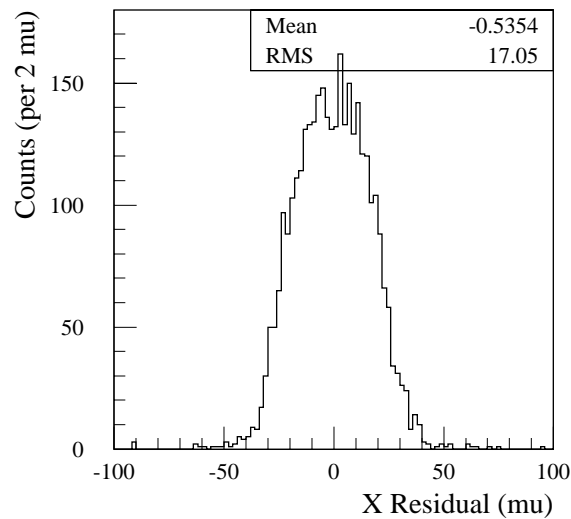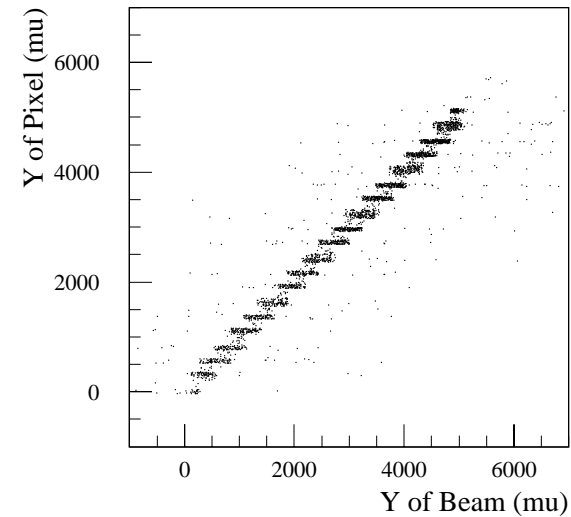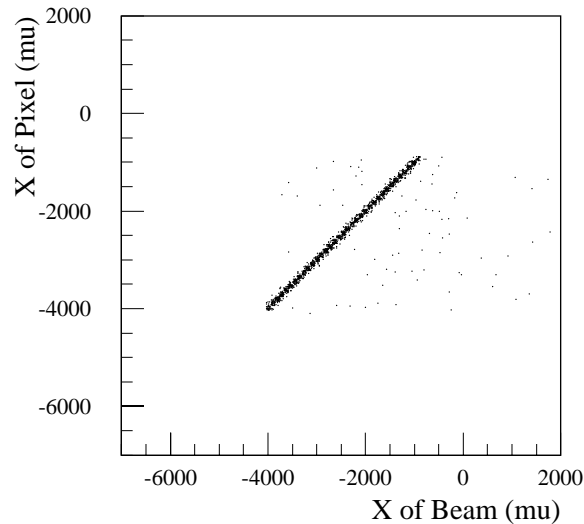
Systematically compare resolutions for different angles (ϕ=0, 10, 20, 30 degrees). First compare x (ϕ direction):

Then compare y (θ direction) for φ=0, 10, 20, 30 degrees:

Entries	2895
Mean	0.9430
RMS	140.8

Y(microns)

Entries	3575
Mean	-0.4895
RMS	124.9

Y(microns)

Entries	3514
Mean	0.1138
RMS	97.38

Y(microns)

Entries	2586
Mean	0.7115
RMS	82.13
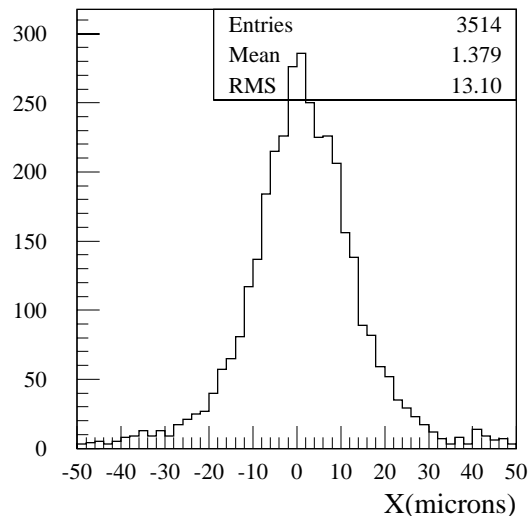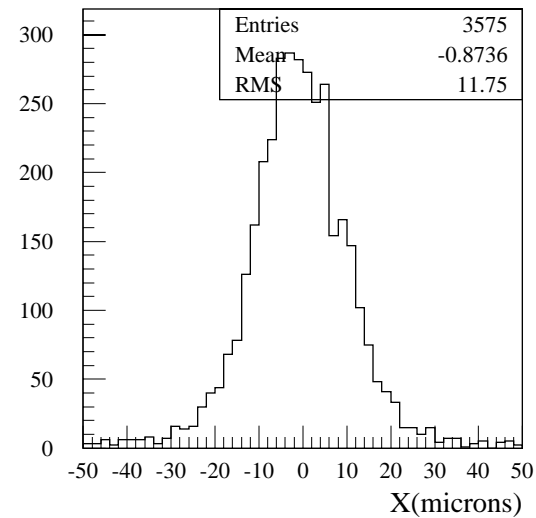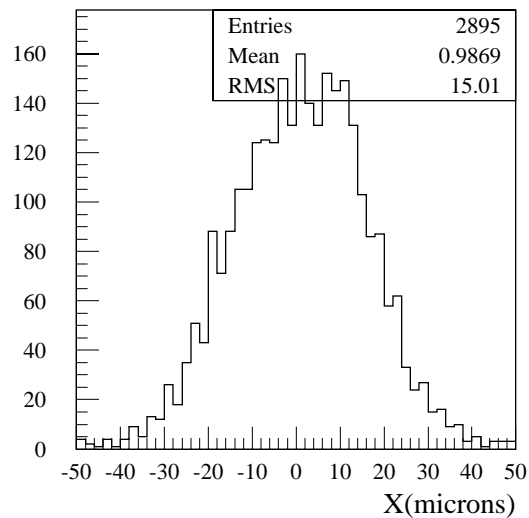
Y(microns)
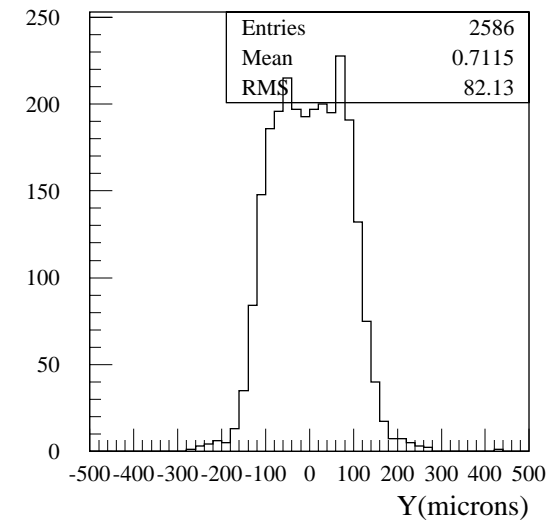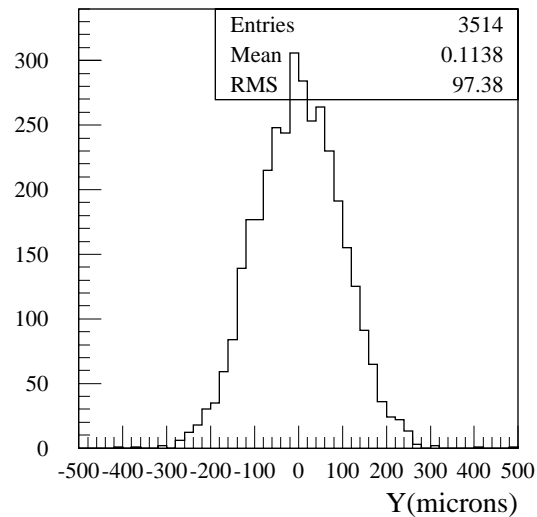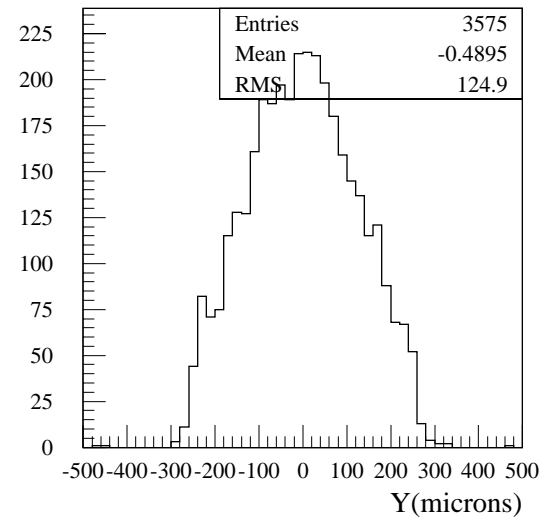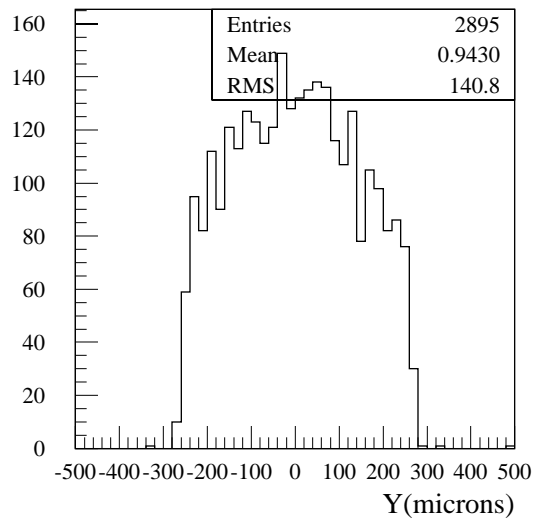
Comments:

- Alignments, etc. are preliminary - much remains to be done

- Present algorithm uses naive analog centroid after charge calibration.

    → This will not give good performance when the cluster width is greater than 2 due to Landau fluctuations in intermediate pixels

    → We will study the binary performance

    → We will also study the analog performance with algorithms that only use charge in the "edge" pixels in a cluster where it is useful, and as a function of quantization of information

- Expect to observe improvement and then degradation in x resolution with ϕ tilt with present algorithms. Would have expected better performance. Present telescope extrapolation error (based on poorly understood covariance matrix) predicts $\approx 7\mu$.

- Expect to observe a y resolution of $\approx 536\mu/sqrt(12) \approx 155\mu$ at zero degrees (modified by diffusive charge sharing). This should improve by almost a factor 2 due to bricking when the ϕ tilt is sufficient to give good charge sharing in that direction. This is also seen.

Efficiency Studies

Preliminary studies of efficiency performed:

- Try to select "good" telescope tracks, and then look for matches with clusters in the pixel array.

- Very tricky given the present large track multiplicity in the telescope, since tracks without matches are often due to pattern recognition errors in strip telescope.

- Initial analysis bounded this efficiency as >95%, but scans indicated that in most cases there was a nearby pixel cluster and suggested tracking problems.

- Improved tracking algorithms presently bound the efficiency as > 98%

- Studies have been done using final 0 degree data taken at various bias voltages (10V, 20V, 40V, and 90V). Expect that the depletion depth varies from about 100μ to 300μ for these studies. Find that results are consistently >98% efficiency, even for 10 V run !

General comment on runs with p-bulk detectors:

- These detectors act very much like heavily irradiated (type-inverted) n^+ on n-bulk detectors, but without the leakage current:

  $\rightarrow$ Oxide charge ensures that region between pixel impants is essentially always depleted, providing good low-capacitance (hence low noise) operation with partial depletion

  $\rightarrow$ This allows us to study resolutions and efficiencies with partial depletion - a significant milestone !

Next Steps

→ **Study improved strip position estimators**

→ **Complete alignment and try to achieve 2-3μ**

→ **Study pulse height distributions with track association**

→ **Study cluster sizes in more detail, including simulation**

→ **Use this to extract $\theta_{lorentz}$ and V_{depl}**

→ **Using final telescope resolutions, study improved position estimators for pixel clusters**

→ **Study remaining losses in tracking to get better efficiency estimate**

Return to H8 later (?) and take more data with p-bulk, and compare to n$^+$ on n-bulk